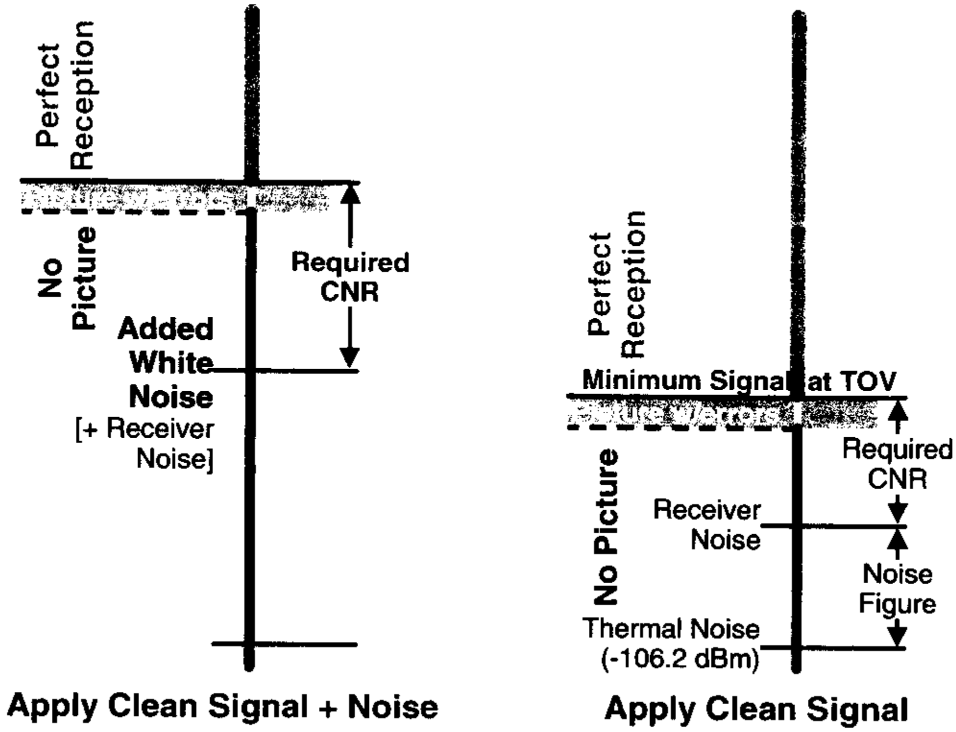

(a) Required CNR *(b) Minimum Signal at TOV*

Figure 5-1. Relationship between Minimum Signal at TOV and Required CNR

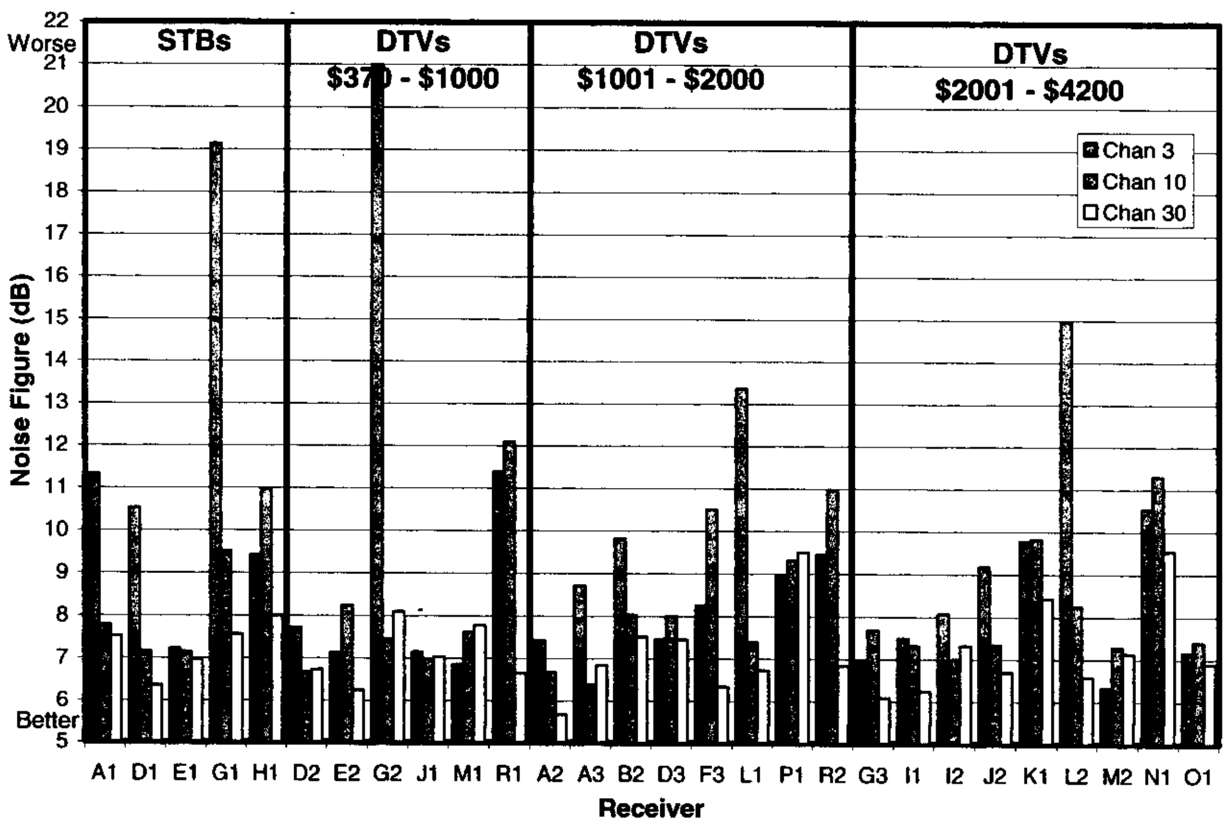

Figure 5-2. Noise Figure on Three Channels

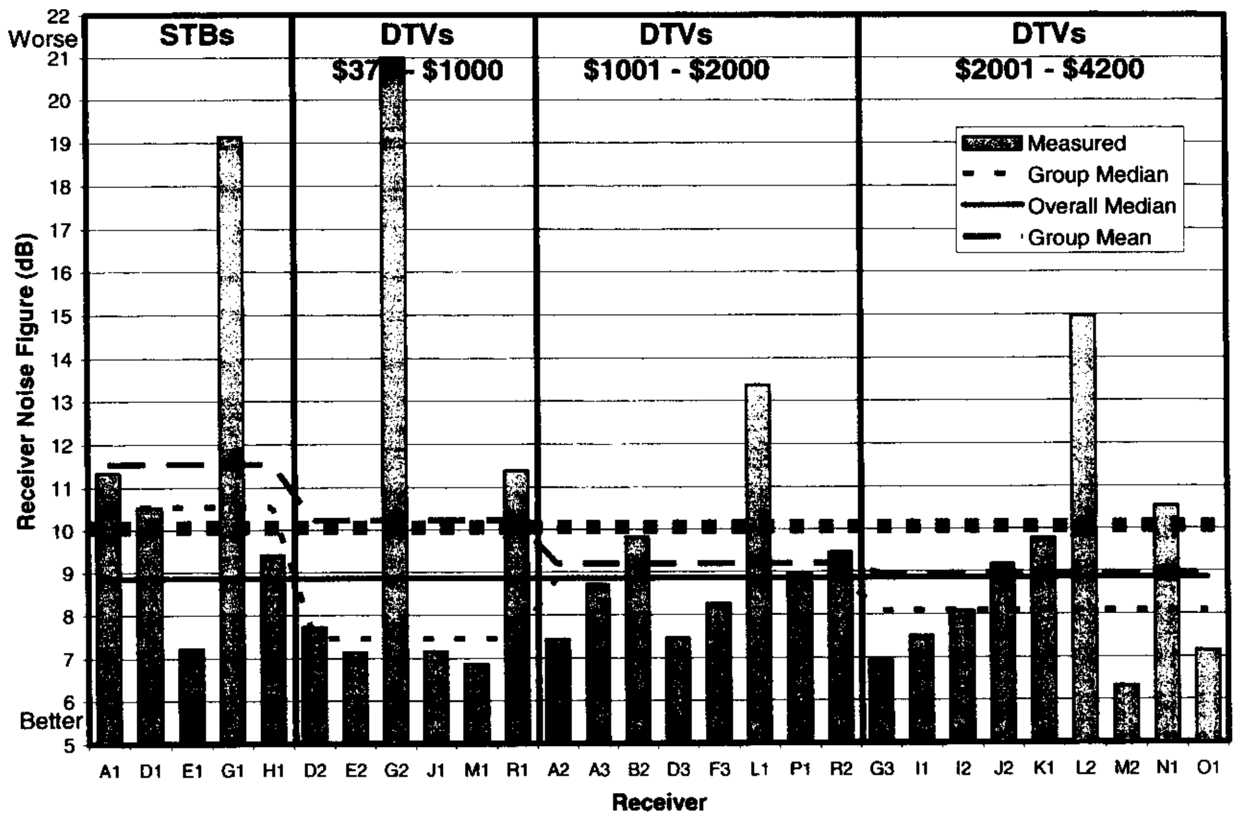

Figure 5-3. Noise Figure on Channel 3 (Low VHF)

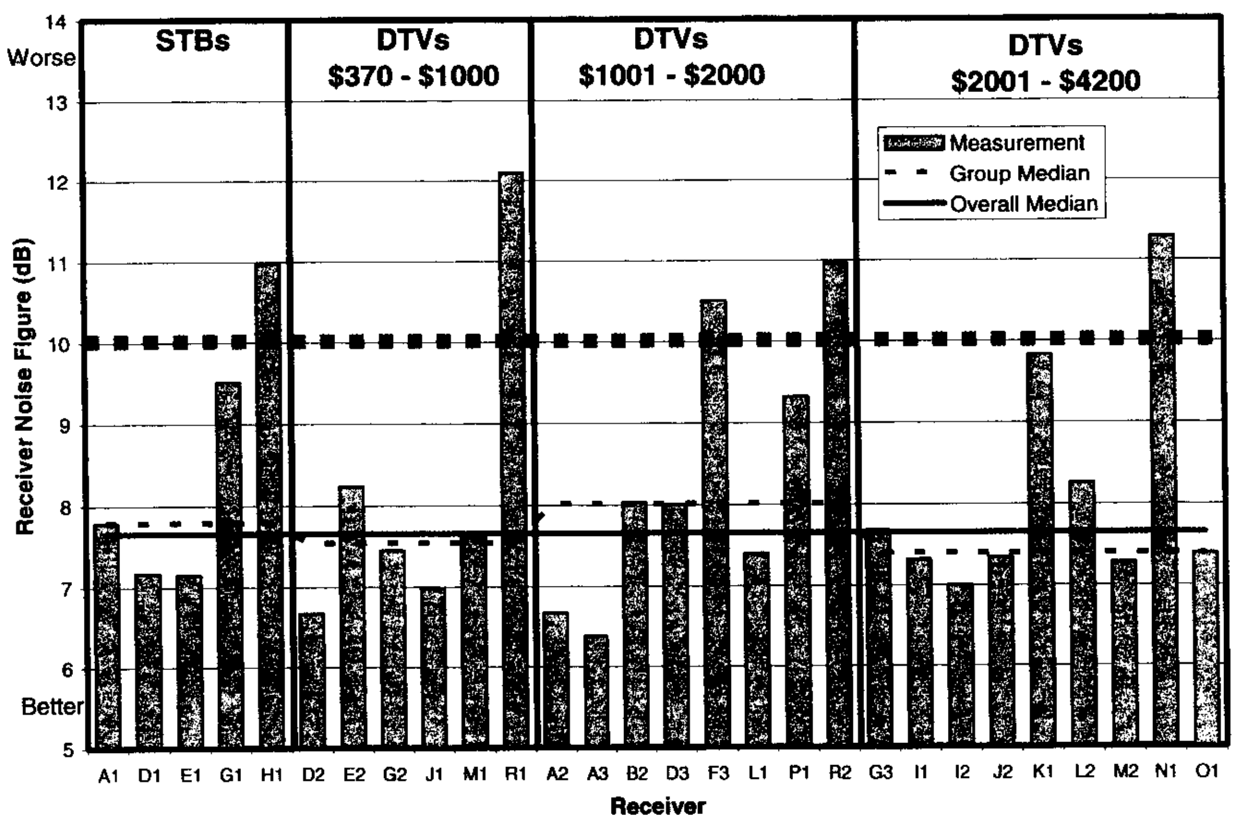

Figure 5-4. Noise Figure on Channel 10 (High VHF)

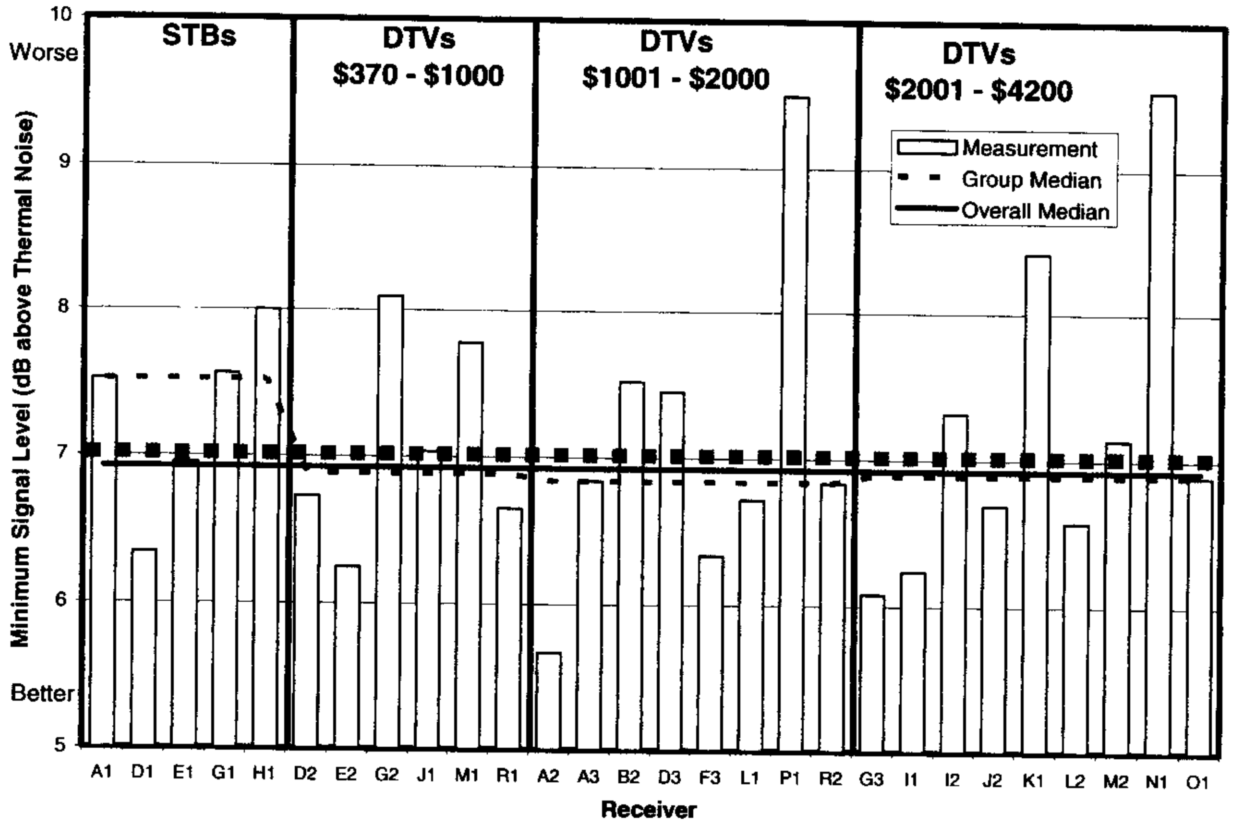

Figure 5-5. Noise Figure on Channel 30 (UHF)

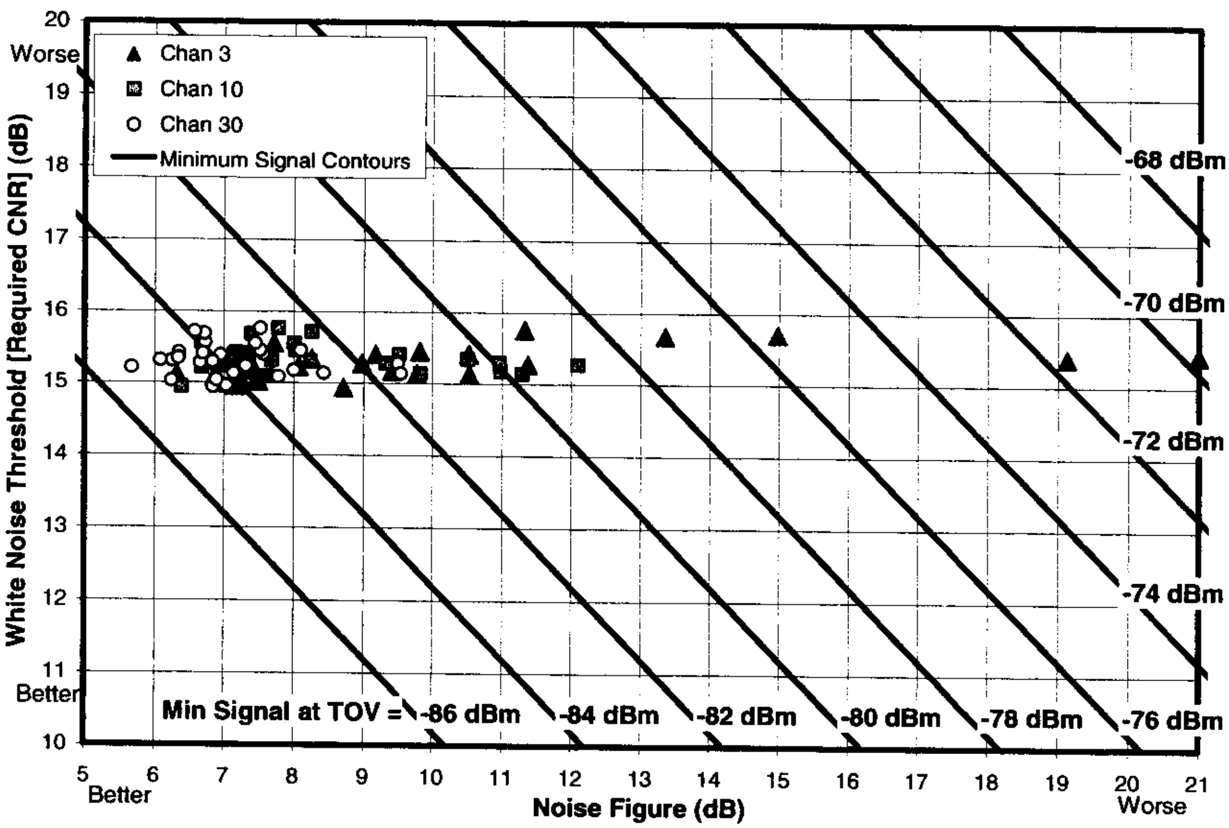

Figure 5-6. Required CNR Versus Noise Figure

CHAPTER 6
PERFORMANCE AGAINST MULTIPATH USING FIELD CAPTURES

Chapters 3 through 5 dealt with over-the-air reception performance of the DTV receivers with a signal that is unimpaired by multipath. Chapter 6 addresses the issue of multipath by determining the ability of each receiver to process broadcast DTV signals that were received and recorded on actual television antennas at various locations in New York City and Washington, DC.

The selected digital RF recordings, also called "captures" or "field ensembles", were 47 of the 50 captures recommended by the ATSC for DTV receiver testing.* ATSC's characterization of the 50 captures is worth noting.

> *"Most of the field ensembles contain data captured at sites where reception was difficult. The field ensembles are clearly not meant to represent the statistics of overall reception conditions but rather to serve as examples of difficulties that are commonly experienced in the field."*†

Three of the 50-recommended captures were excluded from testing with the consumer DTV receivers because they contain no video content and therefore require specially instrumented receivers for testing; however, extrapolation of instrumented receiver test results for those three captures to the consumer receivers is discussed later in this chapter. The remaining 47 captures break down as follows:

- sites characterized as urban (19), suburban (12), rural (2), and various other categories that overlap these designations (14);
- single-family homes (18), townhouses (8), and apartments (21);
- indoor antennas (39) and outdoor log-periodic antennas (8)

Each of the captures was recorded in the year 2000 by the Advanced Television Test Center (ATTC) or the Association for Maximum Service Television (MSTV) using specialized digital capture equipment. Each capture has duration of either 23 or 25 seconds. An RF player allows the recorded signal to be translated to any standard TV broadcast channel and played back as a repeating loop.

Appendix B lists the captures and summarizes some of the test results.

MEASUREMENT METHOD

The test configuration was essentially the same as that described in Chapter 3, for the white-noise threshold measurements, except that no noise was injected. The nine-way splitter allowed the signal to be simultaneously applied to as many as eight DTV receivers and a vector signal analyzer. All 47 selected RF captures were played through each group of receivers. Performance is reported in this chapter as the number of captures successfully played by a receiver for two different criteria of success. As a consistency check, receiver D3 was included in each group of eight receivers that were tested; the numbers of captures played successfully on receiver D3 on the various tests were consistent within one count.

Signal attenuators were adjusted to provide a nominal input of -30 dBm at the receiver antenna ports. The attenuator was not separately adjusted for each capture file; consequently, the actual injected level within

* *"ATSC Recommended Practice: Receiver Performance Guidelines"*, ATSC Doc. A/74, Advanced Television Systems Committee, 17 June 2004.

† Ibid., p. 15.

the channel bandwidth of 6 MHz varied from -38 to -28 dBm based on the level recorded in each capture. All but four of the captures played at an in-channel level within 2 dB of the nominal.

Successful playback of a capture was defined in terms of the number of video error bursts observed during a single playback loop after the loop had played at least three times. (In many cases the performance was monitored over several loops and, if the results varied, a median value was chosen.) A video error burst lasting more than one second was counted based on the approximate duration in seconds. Thus, an error burst lasting three seconds was counted as three errors. Errors occurring during or immediately after the loop-restart time were not counted, nor were errors associated with known defects (dropped symbols) in eight of the captures, as documented by the ATSC.[*]

The testing was performed on channel 30. It should be noted that with many of the DTV receivers, simply tuning to channel 30 was not sufficient to ensure successful acquisition of the TV signal—even with one of the easier captures. The original source material for the captures was recorded from eight different DTV broadcast stations in two cities. Because of the facts that multiple programs can be broadcast on a single channel and that most DTV channels are associated with an equivalent analog channel number that is used in selecting the station (PSIP requirements),[†] many of the receivers were "confused" by changing broadcast stations from playback of one capture to playback of the next, even though the RF channel remained constant. As a result, various methods such as rescanning the channels were necessary to get many of the receivers to operate after changing between captures that originated on different TV channels. To save time in the process, the captures were sorted by originating broadcast station before testing, and were further sorted to allow the more benign captures from a given broadcast station to be played first, in order to lock the receivers onto each new broadcast station.

Further details on the measurement procedure are contained in Appendix A.

RESULTS

Figure 6-1 shows the results of testing each DTV receiver with each of the 47 RF captures. The general format of the plot is as described in Chapter 3 in the section titled, "Format of the Bar Graph Data", but with a few differences. The blue (lower) portion of each bar represents the number of captures that played without a visible error during a single loop of the capture. The upper portion of each bar adds the captures that played with no more than two visible errors during a single loop of capture.

It should be noted that, unlike the plots presented in earlier chapters of this report, increased performance in this plot is represented by taller bars. Also, in addition to the four category groupings of DTV receivers, Figure 6-1 includes an additional bar on the right, labeled 2000REF. This receiver was retained from field testing in the year 2000 and was included in the RF capture testing presented here. Further discussion of this receiver is provided later in this chapter as well as in Chapter 7.

[*] See Table B-1 of this report or the "Quality of Capture" column of the continuation of Figure A-1 on p.28 of "*ATSC Recommended Practice: Receiver Performance Guidelines*", ATSC Doc. A/74, Advanced Television Systems Committee, 17 June 2004.

[†] The Program and System Information Protocol (PSIP) includes a field for establishing this association. Further information is available in Advanced Television Systems Committee documents A/65B "*ATSC Standard: Program and System Information Protocol for Terrestrial Broadcast and Cable (Revision B)*" and A/69 "*ATSC Recommended Practice: Program and System Information Protocol Implementation Guidelines for Broadcasters*" *for more information.*"

Nominal Performance and Variation Among Samples

Unlike the results of other testing presented in this report, the results of testing against the RF captures are heavily clustered into two major performance tiers. The upper-tier (better) performers successfully played about 29 captures without error and about 37 captures with two or fewer errors. The lower-tier performers successfully played about 7 captures without error and about 9 with two or fewer errors. Neglecting receivers D1 and L2, all results fall within ±2 captures of one of these nominal results, as shown in Table 6-1. Receivers D1 and, perhaps, L2, appear to represent an additional performance tier slightly above the lower tier; this tier will be designated as "lower tier+".*

The upper-tier performers represent a quantum leap in ability to handle the most difficult multipath conditions. The receivers that tested in this tier are known to include the latest generation of demodulator chips from at least two of the major DTV chip developers.

Table 6-1. Number of Captures Successfully Played By Each Performance Tier

	Number of Consumer Receivers	Number of Captures Played with No Errors	Number of Captures Played with No More Than 2 Errors
Lower Tier	16	7 ±2	9 +2/-1
Lower Tier+	2	8 and 12	14 and 16
Upper Tier	10	29 ±2	37 ±2

It should be noted that some of the RF captures may contain recording flaws—other than the dropped symbols discussed earlier—that could prevent error-free demodulation regardless of how advanced the demodulator technology may be. For example, four of the captures for which no tested receiver achieved demodulation free of visual errors were identified by the ATSC as having possible non-linearities caused by high-level adjacent channels overdriving the recording system. These or other potential flaws may preclude a 100% success rate on the 47 captures from ever being achieved by any demodulator; consequently, we view the multipath-performance data based on these captures to be useful for purposes of comparing receivers, but not as an absolute measure of performance.

Extrapolation to the Three Captures Lacking Video Content

Three of the ATSC-recommended RF captures lacked video content and could not, therefore, be tested with the consumer DTV receivers; however, they were tested with a five-year-old instrumented DTV receiver, labeled "2000REF" in Figure 6-1. That receiver provides visual and audible indications when segment errors† occur during demodulation of the DTV signal.

Tests were performed first using three captures <u>with</u> video content (labeled as numbers 27, 29, and 45 in Appendix B). These captures exhibited 4, 1, and 2 visual errors, respectively, with the 2000REF receiver.

* Receiver D1 belongs in the "lower tier+" category because it performed above the range of performance for the lower tier both in terms of number of captures played with no errors and number of captures played with two or fewer errors. The case for placing receiver L2 in the "lower tier+" category rather than in the lower tier is weaker, since only one of its performance numbers (number of captures played with two or fewer errors) was above the lower tier range.

† With 8-VSB, each transmission segment consists of one MPEG packet. Thus, a segment error is equivalent to an MPEG packet error.

Results showed a one-to-one correspondence of segment error bursts with observed video error bursts for these captures.*

Tests of the 2000REF receiver with the captures having no video content (labeled 22, 24, and 44 in Appendix B) showed no segment errors. The absence of segment errors indicates that the 2000REF receiver would have exhibited no visible errors on these captures had there been video content to observe. Given that this five-year-old receiver—now obsolete by two demodulator generations—is among the worst performing of the tested receivers in terms of multipath performance (per Figure 6-1), it is considered likely that all of the tested consumer receivers would have exhibited no visual errors for these three captures had there been video content to observe. Consequently, if one wanted to extrapolate performance against the entire set of 50 ATSC-recommended RF captures from the tests of the 47 with video content, it is likely that three zero-error successes should be added to the results for each receiver.

Variation With Product Type and Price

Interestingly, both upper-tier and lower-tier performers appear in all three price categories of DTVs. This suggests that performance is not a function of price—at least in the DTV category.

On the other hand, none of the set-top boxes—the least expensive way to receive a digital broadcast if you connect it to an existing television—perform at the upper tier level.

Some understanding of these results can be achieved by looking at the introduction date of each tested receiver to the U.S. market. Introduction dates (by month and year) for 25 of the 28 receivers tested for this report were provided by the manufacturers; the remaining three were determined by a web search. Though introduction dates are not reported here in order to avoid possible date-based linking of individual product models with the receiver designations used in this report, the following observations are relevant.

- All ten upper-tier performers were introduced in or after March, 2005.
- The set-top boxes—all of which performed at the lower tier or "lower tier+"—were introduced in or before November, 2004.
- Of the lower-tier or lower-tier+ integrated DTVs (i.e., excluding set-top boxes), two were released in the latter part of 2004 and the remaining eleven were introduced between March and July, 2005.

Since the set-top box models available on the market at the time of the reported tests were 2004 or earlier models,† their lower-tier or "lower-tier+" performance reflects the lack of availability of the newer generation of DTV demodulator chips at the time of product design.

Among the DTVs, it is clear that introduction dates in or after March 2005 are consistent with feasibility of including of the newer technology. Among the tested DTVs that were introduced in or after March 2005, 48 percent performed at the upper tier level. It is probable that some of the products introduced in this time frame carried over tuner/demodulator designs from a previous generation.

One would expect that, as future models are released, the newer generation demodulator technology will migrate to an increasing extent into all DTV product categories, including set-top boxes, and that, at some point in the near future, the improved technology will be contained in all newly introduced receivers. In the meantime, there is little publicly available information to assist those consumers who live in locations

* In general, visual errors are expected to occur only when segment errors occur, but the reverse is not always true, depending on effectiveness of MPEG error concealment algorithms for the video content at the time of the errors.

† One of the tested set-top-box models was released to the market in August 2003. The other four were released between July and November 2004.

characterized by challenging multipath conditions in selecting DTV receivers that achieve the upper tier of performance.

Relationship Between Multipath Performance and White Noise Threshold

There is some reason to expect that improvements in multipath performance—which is achieved in part by increasing the number of taps in the demodulator's equalizer circuit—might come at the expense of poorer white noise threshold, because, even in the absence of multipath, the additional taps could be expected to add noise that is related to carrier amplitude. (Since an automatic gain control would be expected to provide sufficient gain to amplify the input signal—whatever its level—to a fixed level for processing by the demodulator, one would expect that the tap noise generated after this variable amplification would be at a fixed level relative to the DTV signal rather than at a fixed level relative to the antenna input—hence the impact would appear as a degradation to required CNR [white noise threshold] rather than an increase in noise figure.)

Figure 6-2, shows the measurements of white noise threshold (from Chapter 3) plotted against multipath performance as measured by the number of RF captures (out of 47) that were successfully played without error. The lower tier of multipath performers (presumably containing earlier generation 8-VSB decoders) had a median CNR threshold of 15.3 dB,[*] which is slightly worse than the 15.19 dB threshold achieved by the ACATS Grand Alliance prototype receiver.[†] Until the most recent VSB decoder generation came to market, the trend of the earlier VSB decoder improvements was a very slight worsening of the CNR at threshold as a tradeoff for improved multipath performance. The 15.1 dB median CNR threshold for the upper tier of multipath performers suggests that this trend is over. In fact, the seven best-performing receivers in terms of white noise threshold are in the upper tier of multipath performance.

[*] 15.3 dB is the median value for those receivers identified as lower tier—not including those identified as "lower tier+". If the lower tier+ receivers are included, the median is 15.4 dB.

[†] "Final Technical Report", Federal Communications Commission Advisory Committee on Advanced Television Service (ACATS), October 31, 1995, p.19.

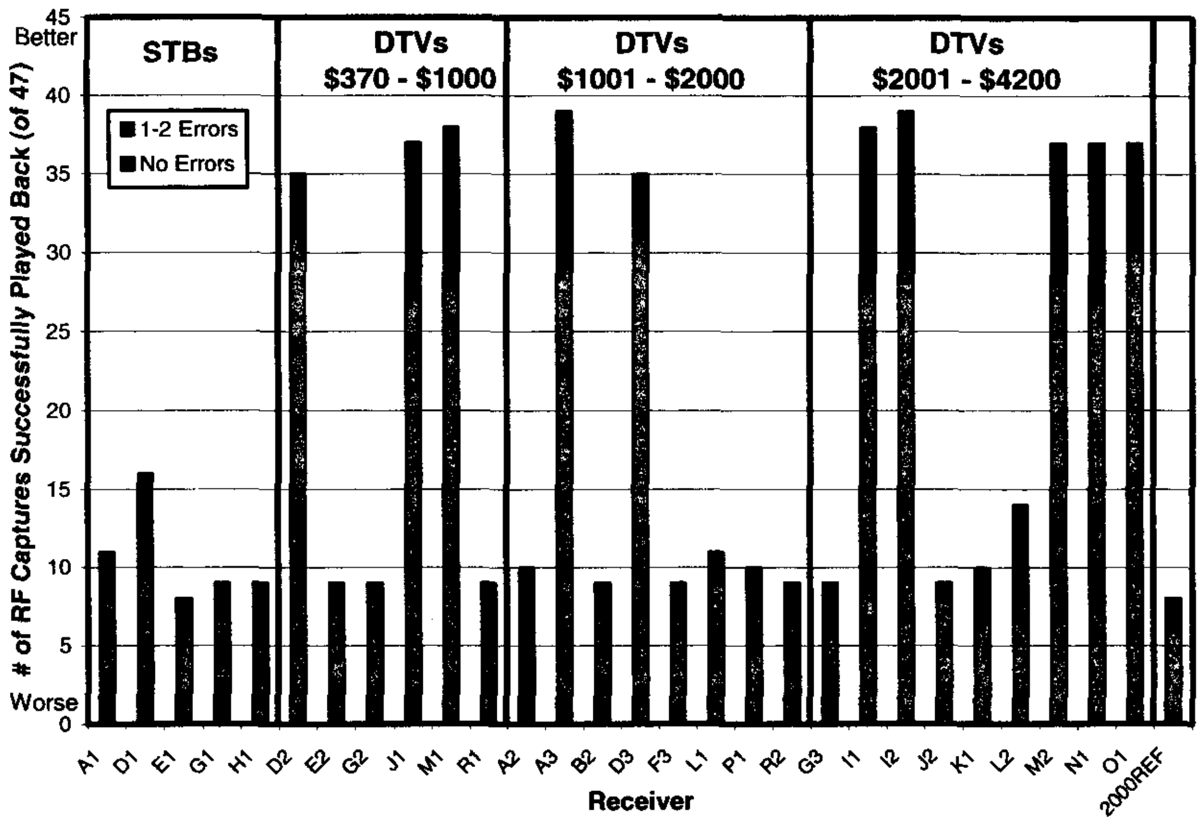

Figure 6-1. Performance Against 47 RF Captures

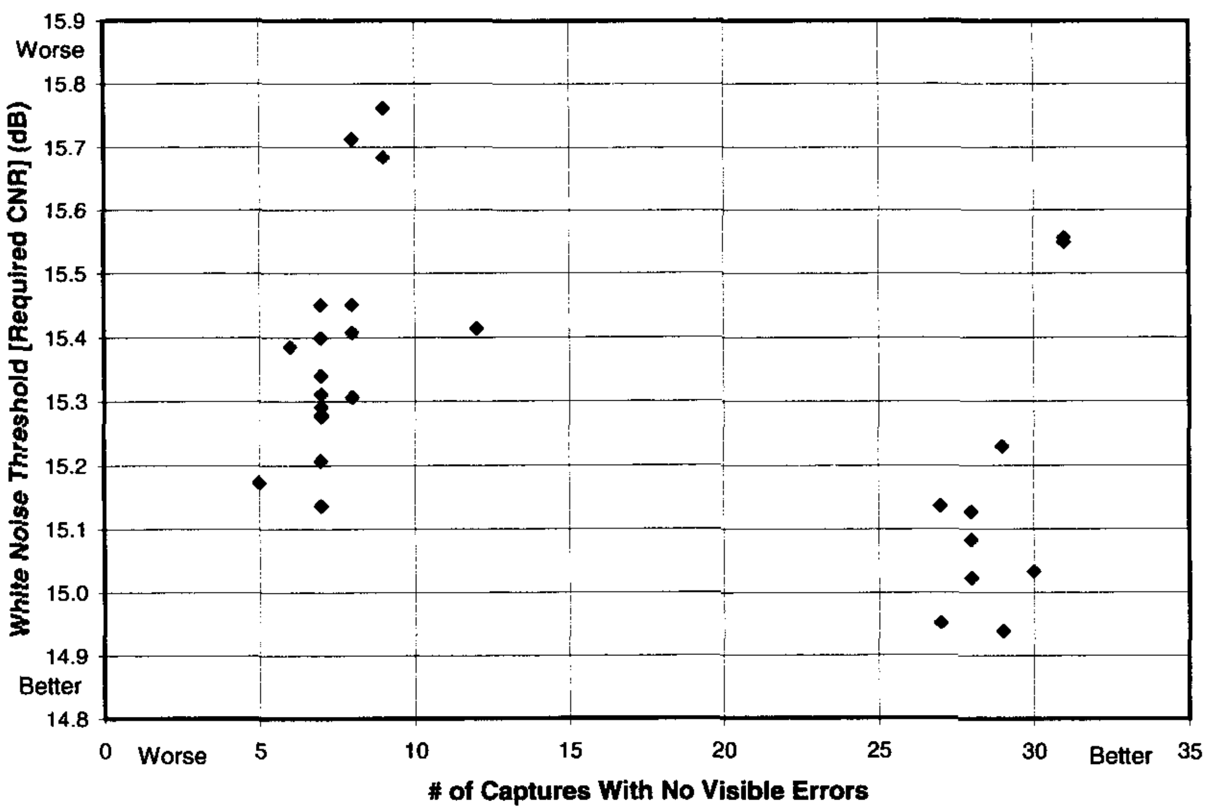

Figure 6-2. White Noise Threshold Versus Multipath Performance

CHAPTER 7
INFERRED PERFORMANCE AGAINST REPRESENTATIVE MULTIPATH CONDITIONS

The measurements presented in the previous chapter show that DTV receivers on the market at the time of these tests differ markedly in their ability to handle certain difficult multipath conditions. In order to understand the impact of these differences, one would also like to know how prevalent are the types of multipath conditions that differentiate receiver performance. If those conditions occur only rarely, then the performance differences will not be of consequence to most consumers; on the other hand, if they occur frequently, then the performance differences between "upper tier" and "lower tier" performers will radically affect many consumers.

Although an investigation of the frequency of occurrence of various multipath conditions is beyond the scope of this report, some of the measured data presented in Chapter 6 can be combined with results from a year-2000 FCC field investigation to provide at least a partial answer.

MULTIPATH CAPABILITY BASED ON YEAR-2000 FIELD TESTS

In 2001, the FCC Laboratory reported the results of year-2000 field tests of DTV coverage in Washington, DC and of DTV receiver performance.[*] In that study, the performance of six DTV receivers was evaluated at 60 locations for reception of two broadcast UHF DTV stations (channels 34 and 48). Nine of the locations were specifically selected for high-multipath conditions; however, 51 locations—referred to as "coverage sites", were selected in ways that can be expected to yield more representative results. It is these 51 sites that are of interest for the current analysis.

Of the 51 coverage sites, 38 were located at five-mile intervals along radials from the broadcast antenna of digital channel 48 in Washington, DC. The other 13 coverage sites were chosen from sites randomly selected from within a box 17.5 miles on a side, centered on the same broadcast antenna.[†]

At each site, reception performance measurements were made using at least two antenna systems:
- a log-periodic, outdoor-type antenna on a 30-ft. mast, and
- one of two indoor-type antennas on a 7-ft. tripod located outdoors.

The tripod-mounted antenna measurements were intended to indicate reception performance that could be expected with an antenna located indoors to the extent that could easily be determined given that access to homes or other buildings at randomly selected sites is not generally available. Though the antenna was not located indoors, the height and antenna type were consistent with indoor use. In general, a bow tie antenna was used as the "indoor-type" antenna. If the bow tie failed to achieve reception, a small, indoor, UHF log-periodic antenna ("Silver Sensor") was tried.

[*] Inglis, William H. and Means, David L., *"A Study Of ATSC (8-VSB) DTV Coverage In Washington, DC, And Generational Changes In DTV Receiver Performance"*, Interim OET Report FCC/OET TRB-00-2, Technical Research Branch, Laboratory Division, Office of Engineering and Technology, Federal Communications Commission, April 9, 2001.

[†] More specifically, 200 sites were randomly selected within the 17.5-mile box. The tested sites were selected from among these—focusing on sites located in Washington, DC and sites near the FCC Laboratory, in Columbia, MD.

The tests included six DTV receivers, one of which was an instrumented prototype receiver to be used as a reference. Initially, the reference receiver was a second-generation Zenith ProDemodulator. After two thirds of the testing was complete (on July 17, 2000), that receiver was replaced with a third-generation Zenith ProDemodulator. The third generation included an equalizer with longer ghost cancellation times and slightly improved pre-ghost performance at the expense of slightly degraded white noise performance, relative to the second generation.

That same third-generation receiver was tested this year, along with the 28 current-generation consumer receivers, to determine performance against the 47 RF captures, as described in Chapter 6. The result for the third generation reference receiver is shown as the right-most bar (labeled "2000REF") of Figure 6-1. In the current tests, that receiver—with equalizer technology now two generations behind the latest technology—tied for either the worst or second worst performance (depending on whether counting the zero-error data or the two-error data) when included with the current crop of receivers that were tested. Given that the third generation was used for only one third of the year-2000 tests and that a second generation receiver—with inferior equalizer technology—was used for two thirds of those tests, one can assume that the reported field test results for the "reference receiver" from those earlier tests correspond to receiver with multipath performance at or below the level shown by the "2000REF" bar in Figure 6-1.

In the year-2000 tests, all but one of the 51 sites exhibited field strengths judged to be large enough for theoretical DTV reception.* Using the mast-mounted, outdoor-type antenna, the reference receiver received channel 34 with no visible picture errors in all 50 of those sites and received channel 48 without visible errors in 49 of the 50 sites. Thus, the reference receiver successfully handled multipath conditions in 99 percent of the test-site/broadcast-station combinations with the mast-mounted antenna. When using the tripod-mounted indoor-type antennas (including the Silver Sensor, when needed), the reference receiver handled 85 percent of the test-site/broadcast-station combinations without visible picture errors

Thus, receivers performing at or below the level of the 2000REF receiver shown in Figure 6-1 were able to successfully handle 99 percent of the multipath situations in the "coverage tests" when using a mast-mounted outdoor antenna. Though the tests involved only one metropolitan area and the sample size was too small to consider these numbers statistically accurate, the sites selected are expected to be far more representative of randomly selected real world conditions than the ATSC-recommended sites, which were chosen because of their difficult multipath conditions. Given that the 2000REF results show performance at or below almost all of the lower-tier performers in the Figure 6-1, one can reasonably assume that, even lower-tier multipath performance (as defined in Chapter 6) is adequate to handle the vast majority of reception conditions (at least in the Washington, DC area) when the receiver is paired with a good outdoor, mast-mounted antenna.

Similarly, receivers performing at or below the level of the 2000REF receiver shown in Figure 6-1 were able to successfully handle 85 percent of the multipath situations in the "coverage tests" when using a indoor-type antenna at a 7-foot height (but located outdoors). It appears likely, then, that multipath performance at the lower tier of Figure 6-1 may be adequate for most locations in conjunction with an indoor antenna, but that improved multipath performance (e.g., the upper tier of Figure 6-1) might offer benefits in many locations.

IMPACT OF REPRESENTATIVE MULTIPATH ON REQUIRED CNR

The year-2000 field tests also offer some insight into the impact of multipath on required CNR for a receiver.

* With the mast-mounted antenna, 51 sites were tested. With the tripod-mounted antennas, 50 sites were tested. In both cases, all but one site had sufficient field strength for theoretical DTV reception.

Those tests included measurements of required CNR at each site. The required CNR was determined by adding white Gaussian noise to an amplified version of the signal received from the antenna and adjusting the noise level until the threshold of visibility (TOV) was observed.

Though the precision of the measurements was limited by the use of one-dB steps in adjusting the noise level, the median required CNR across all of the coverage sites provides an indication of the required CNR in real world multipath conditions. In general it was found that the newer generation receivers performed better—i.e., had a lower required CNR—that older generation receivers. When used with the mast-mounted antenna, the newest generation receiver that was used throughout the test period for the 2001 report (a "third generation" receiver identified as receiver 5 in that report) exhibited a median required CNR of 15.9 dB across all "coverage sites" tested for one of the received broadcast stations and 16.0 dB for the other. With the tripod-mounted antennas, the corresponding numbers were 17.0 and 16.6 dB.

Absent better information, a required CNR of 16.0 dB may be a reasonable estimate of reception performance in typical multipath conditions if an outdoor antenna is used.

CHAPTER 8
SUMMARY AND CONCLUSIONS

The laboratory-based measurements performed for this report emulated two types of over-the-air reception conditions for DTV receivers:

(1) Unimpaired signal (i.e., no multipath) [Chapters 3 – 5], and

(2) Signal impaired by multipath (ghosts) [Chapter 6]—focussing on particularly difficult multipath conditions.

The unimpaired signal measurements can be used to quantitatively predict receiver performance under benign reception conditions—i.e., with little multipath. The multipath tests provide a basis for comparing the ability of different DTV receivers to handle difficult multipath conditions—without directly addressing the frequency of occurrence of those multipath conditions.

The linkage developed in Chapter 7 between the new, laboratory-based measurements performed for this report and earlier FCC field-test data provides a basis for anchoring the multipath results to representative, real-world reception conditions.

The purpose of this report has been to provide an empirical basis for answering three questions that derive from study requirements imposed by Congress as part of SHVERA [Chapter 1]. Those questions are as follows.

(1) Is there is a wide variation in the ability of reasonably-priced consumer digital television sets to receive over-the-air signals, such that at a given signal strength some may be able to display high-quality pictures while others cannot?

(2) Is such variation related to the price of the television set?

(3) Should such variation be factored into setting a standard for determining whether a household is unserved by an adequate digital signal?

In addressing these questions, separate answers will be provided for benign signal conditions (little multipath) and difficult multipath conditions. The third question will be addressed by comparing measured results to the receiver performance planning factors in OET-69.

The benign signal case will be evaluated in terms of the measured values of minimum signal at the threshold of visibility of errors (TOV) for the receivers. This specifies the ability of a DTV receiver to operate with a weak signal—absent significant multipath or interference. To provide a better understanding of differences among receivers, the discussion will also delve into two receiver parameters that combine to determine the minimum signal at TOV. These are:

- the white noise threshold (required carrier-to-noise ratio [CNR]); and
- the effective noise figure of the receiver.

The first of these characteristics is a demodulator characteristic that is independent of which TV channel contains the signal of interest. The second is a measure of the internally generated electronic noise of the receiver; it <u>does</u> vary with TV channel. In reporting channel-dependent data, results are presented for the low-VHF, high-VHF, and UHF bands, which were represented in the measurements by TV channels 3, 10, and 30.

VARIATION IN RECEPTION PERFORMANCE

For Benign Signal Conditions

In the low-VHF band, the variation in reception performance among the tested DTV receivers was moderately high. The minimum signal level at TOV exhibited a 3.7-dB standard deviation among the receivers. 89 percent of the receivers exhibited performance within 5.1 dB of the median performance, but two (seven percent) same-brand receivers were significantly worse than the median—by 10.6 and 12.5 dB. Omitting those two receivers from the data set would reduce the standard deviation to 2.3 dB.

In the high-VHF and the UHF bands, the variation in reception performance among the tested receivers was small. In the high-VHF band, the minimum signal level at TOV exhibited a 1.6-dB standard deviation; 89 percent of the receivers exhibited performance within 3.1 dB of the median, and the poorest performing receiver exhibited a performance level 4.3 dB worse than the median. In the UHF band, the minimum signal level at TOV exhibited a 0.9-dB standard deviation; 89 percent of the receivers exhibited performance no worse than 1.3 dB poorer than the median, and the poorest performing receiver exhibited a performance level 2.5 dB worse than the median.

Most of the variation in reception performance among the tested receivers was due to differences in receiver noise figure rather than in required CNR. The noise figure variations were larger than the required-CNR variations by factors ranging from 4.2, in the UHF band, to 16, in the low-VHF band.

For Difficult Multipath Conditions

Independent of band, there was a wide variation in ability of the receivers to handle difficult multipath conditions; however, linkage of the current results with earlier field test results suggest that the observed performance differences are of no consequence in the vast majority of reception locations, if an outdoor, mast-mounted antenna is used. When an indoor antenna is used, the linkage suggests that the observed performance differences would be significant in many, but probably not most, locations.

In tests against RF captures recorded from antennas at sites specifically selected for their challenging multipath conditions, the multipath-handling capability of the receivers fell primarily into two tiers of performance. The upper (better-performing) tier included ten receivers. The lower tier included 16 receivers. Two receivers fell in between the two tiers, but closer to the lower tier. The upper-tier receivers were able to handle about four times as many of the RF captures as the lower tier.

The FCC's year-2000 field tests at 51 sites that were selected without regard to multipath—and thus more likely to be representative of the typical range of common reception conditions than the RF captures—can be used to put the current multipath test results in perspective. A now-obsolete instrumented receiver left over from those earlier field tests was retested this year against the RF captures and was found to perform at the bottom of the lower performance tier. But, in the year 2000 field tests that now-inferior receiver successfully handled multipath in 99% of the combinations of site and broadcast station,[*] when a mast-mounted outdoor antenna was used. The success rate dropped to 85 percent when an indoor-type antenna was used,[†] indicating an increased likelihood that better multipath performance in the receiver would have helped.

[*] Out of the 50 sites that had sufficient field strength for theoretical DTV reception.

[†] The indoor antenna was mounted at a 7-foot height, consistent with indoor antenna, but tests were performed outdoors.

PRICE-DEPENDENCE OF RECEPTION PERFORMANCE

For Benign Multipath Conditions

In assessing the price-dependence of receiver performance, one must consider two things:
(1) whether an observed variation of performance with price among the tested receivers is statistically significant—i.e., whether it represents a real trend among DTV receivers currently on the market or whether it is a statistical artifact of the particular selection of receivers that were tested; and,
(2) whether an observed variation of performance with price is of sufficient magnitude to significantly affect television performance.

In the low-VHF band, though the variability in performance among the receivers was moderately high, the variability among the price categories was small, and no statistically significant price-dependence of that variation was found. In fact, the median performance of the low-cost TVs was slightly better than that of either the mid-priced or high-priced TVs. The median performance of the tested set-top boxes was poorer than that of the integrated DTVs by 2.3 dB, though it must be noted that these were older designs (2004 and earlier models that were still on the market at the time of this report) than the DTVs.

In the high-VHF and the UHF bands, the variation in reception performance with price was judged to be both small and not statistically significant. The median performance of the high-cost TVs differed from that of the low-cost TVs by less that 0.2 dB. Set top boxes exhibited median performance 0.6 dB and 0.7 dB worse than the median of all TVs in the low-VHF and UHF bands, respectively.

For Difficult Multipath Conditions

The tested receivers fell into two distinct tiers of multipath-handling capability—the upper tier representing a significant performance improvement associated with at least two companies' newest generation of demodulator chips.

Given that both tiers of performance appeared in all three price ranges of DTV receivers, there appears to be no inherent price dependence among the DTVs; however, there was a complete absence of upper-tier performers among the tested set-top boxes. This absence is attributed to the older designs of the set-top box products—all of which were introduced in the year 2004 or earlier. Among the tested receivers, none that were introduced before March 2005 were found to exhibit upper-tier performance, whereas 48 percent of those introduced in or after that month performed at the upper tier level.

RECEPTION PERFORMANCE RELATIVE TO OET-69

For Benign Multipath Conditions

The results show no clear need to adjust planning factors in OET-69 for application to SHVERA. Table 8-1 shows that, for benign multipath conditions, the poorest performing receiver category—*set-top boxes*—exhibited median performance (as indicated by minimum signal at TOV) closely matching predictions based on current OET-69 planning factors, with median performance exceeding the OET-69 predictions by 1.7 dB in high VHF and falling below OET-69 performance levels by less than 1 dB in low VHF and UHF. The median low-cost DTV performance matched OET-69 in the UHF band and was better than OET-69 by about 2 dB in the VHF bands. It should be noted that the tolerance on these measurements is about ±1 dB.

[It is also noted that, in terms of minimum signal at TOV, the overall median performance of the tested receivers (-82.2, -83.2, and -83.9 dBm, in low VHF, high VHF, and UHF, respectively) matches, within measurement accuracy, the minimum performance standard of -83 dBm recommended by the ATSC.*]

Table 8-1. Net Performance for Unimpaired Signal Relative to OET-69 Model

Band	Median of All Test Samples	Median Low-Cost DTV	Median Set-Top Box
Low VHF (Ch.3)	1.2 dB better	2.3 dB better	0.7 dB worse
High VHF (Ch.10)	2.2 dB better	2.4 dB better	1.7 dB better
UHF (Ch.30)	0.1 dB worse	0.1 dB better	0.8 dB worse

A breakdown of the results by individual planning factors is shown in Table 8-2. Median required carrier-to-noise ratios (CNRs) closely match the OET-69 value, as does the system noise figure in UHF. The median VHF noise figures of the tested receivers were better than the OET-69 values, with the exception of the set-top box median in low VHF, which was only 0.5 dB above (worse than) the OET-69 value.

Table 8-2. Planning Factor Measurements with Unimpaired Signal

Planning Factor	OET-69	Overall Median of Test Samples	Median Low-Cost DTV	Median Set-Top Box
Required Carrier-to-Noise Ratio (dB)	15.2†	15.3	15.3	15.4
System Noise Figure (dB) in Low VHF	10.0	8.8	7.4	10.5
System Noise Figure (dB) in High VHF	10.0	7.6	7.5	7.8
System Noise Figure (dB) in UHF	7.0	6.9	6.9	7.5

Note: for all parameters, lower values correspond to better performance

Adjustment for Multipath

The required CNRs presented above were measured for an unimpaired signal. In the presence of significant multipath, it is known that higher CNRs are required. We have performed no measurements of this effect on the current generation of receivers; however, field tests from the year 2000 yielded a value of 16 dB for the median required CNR across 50 test sites using the then newest generation of DTV receiver hardware and an outdoor, mast-mounted antenna. This is only 0.7 dB above the median measured value from the receiver tests using a benign signal. If the net performance data of Table 8-1 were degraded by 0.7 dB to reflect this value for required CNR, it can be seen that the results would still closely match OET-69 predictions.

* "ATSC Recommended Practice: Receiver Performance Guidelines", ATSC Doc. A/74, Advanced Television Systems Committee, 17 June 2004, p.11.

† See note for Table 1-1.

Overall Conclusion Regarding Adjustment to Planning Factors

While adjustments to the OET-69 planning factors could be made based on the test results presented in this report in combination with results from the year-2000 field tests, the overall effect on performance predictions would be small. Combining the 16-dB required CNR value, as discussed above, with the overall median noise figures would yield more optimistic predictions that the current OET-69 by 0.4 dB and 1.6 dB, respectively, in the low-VHF and high VHF bands, and less optimistic predictions by 0.7 dB in the UHF band. Given the tolerances on the measurements, such adjustments to the existing methodology are not recommended.

APPENDIX A:
TEST CONFIGURATIONS, ISSUES, AND PROCEDURES

TEST CONFIGURATIONS

This appendix provides additional information regarding test configurations, procedures, and issues that arose during the testing.

General Information on the Test Configurations

All test and measurement setups maintained a 50-ohm impedance throughout, except at the signal source and the consumer TV inputs, which were each specified to be nominally 75 ohms. (An older, instrumented reference receiver identified as 2000REF in this report had a 50 ohm input impedance.) The 75-ohm devices were matched to the rest of the test setup through minimum-loss impedance-matching pads, except that, in the test setup that employed a splitter, an impedance-matching transformer was used at the signal source to reduce losses.

Attenuation pads were used throughout each test configuration to reduce the effects of any impedance mismatches at places where such mismatches were considered likely or would be expected to have a significant impact. A 50-to-75-ohm impedance-matching pad used at the input of each consumer DTV receiver served both as an impedance-matching device and as a 5.8-dB attenuator to attenuate reflections due to deviations of the TV antenna inputs from the nominal 75-ohm value.*

Splitter Test Configuration

Figure A-1 shows a block diagram of the "splitter test configuration", which was used for tests of white noise threshold and multipath performance.

An RF player (Sencore RFP-910) playing the "Hawaii_ReferenceA" file supplied with the player was used as the ATSC 8-VSB signal source, for reasons discussed in the "Test Issues" section of this appendix. Amplifiers for the signal operated at RMS levels that were more than 17-dB below the specified 1-dB compression points in order to ensure linearity.

For the white noise tests, noise was supplied by a noise generator, which was then externally filtered to roll off the noise beyond 700 MHz—well above the tested frequencies.

Both signal and noise levels were adjusted using step attenuators that could provide 0 to 81 dB of attenuation in 0.1-dB steps.

Signal and noise were combined using a directional coupler, then divided nine ways by means of two cascaded layers of three-way splitters, each specified to have a minimum isolation of 14 dB between inputs. The splitters were followed by 25-foot long, well-shielded, low-loss cables, each of which drove either an impedance-matching pad (nominally 5.8-dB power attenuation) for connection to a consumer TV receiver or a 50-ohm attenuator pad (nominally 6-dB attenuation) for connection to measuring instruments or to the instrumented receiver. The nine outputs—at the output of the final pads—are designated by port numbers Pt1, ... Pt9 when the final pad is an impedance-matching pad, as when driving a consumer DTV. An "a" is suffixed onto the port numbers when the final pad is a 50-ohm pad,

* The intent was both to minimize standing waves on the 25-foot, low-loss cables and to reduce the impact of RF energy reflected back from a poorly matched TV on signals delivered to other TVs through the splitter.

as when driving a measurement instrument (vector signal analyzer or spectrum analyzer) or an instrumented receiver having a 50-ohm input impedance. Port Pt5a was always used as the measurement port.

The splitter arrangement allowed the signal and noise to be simultaneously delivered to as many as eight TVs and to a vector signal analyzer used for measurements. Any amplitude mismatch between the various ports, though small, was not of concern because the signal levels for multipath testing were not critical and because white noise threshold tests involve the ratio of two measurements (signal and noise) that were made on the same port and using the same amplitude range of the spectrum analyzer to eliminate the effect of small errors in absolute measured levels.

Minimum Signal Test Configuration

Figure A-2 is a block diagram of the configuration used for measuring minimum signal at TOV.

An RF player (Sencore RFP-910) playing the "Hawaii_ReferenceA" file supplied with the player was used as the ATSC 8-VSB signal source, for reasons discussed in the "Test Issues" section of this appendix.

Because minimum input signal at TOV is an absolute measurement rather than a ratio, a signal splitter was not used for these tests. The 25-foot low-loss coaxial cable carrying the signal was connected through a 10 dB attenuator and an impedance matching pad (50 to 75 ohms, 5.8 dB power attenuation) to the TV input. After signal level was adjusted to achieve TOV on the TV, the cable and 10-dB pad—but not the impedance matching pad—were moved to the vector signal analyzer input for the signal level measurement, which then had to be corrected for measured loss of the impedance matching pad.

CALIBRATION AND SIGNAL QUALITY TESTS ON TEST SETUPS

Impedance-Matching Devices

The power loss of 14 identical minimum-loss impedance-matching pads (Trilithic model ZM-57) and two impedance-matching transformers (Trilithic ZMT-57) were measured as a function of frequency. The devices were labeled with individual numbers for identification; designations were MLP#1 through MLP#14 for the minimum-loss impedance-matching pads and TT#1 and TT#2 for the transformers.

The losses of the individual impedance matching devices were determined from loss measurements performed on back-to-back pairs of impedance-matching devices. These measurements were performed by measuring signal levels versus frequency for a tracking generator signal and for that signal as attenuated by a back-to-back pair of impedance-matching devices (50 ohms to 75 ohms to 50 ohms) to determine the loss versus frequency for each tested pair of devices. (Loss was computed by subtracting the measured output level versus frequency of the tested devices from the output level versus frequency of the tracking generator, measured with the same spectrum analyzer settings [including input attenuation and reference level] in order to ensure that loss measurements were accurate.) The measured combinations included MLP#13 with each of the other devices and MLP#14 with each of the other devices. The difference between losses of MLP#13 and MLP#14 was computed as the difference between average loss of the combinations of MLP#13 with MLP#1 through MLP#12 and average loss of the combinations of MLP#14 with MLP#1 through MLP#12. The loss of MLP#13 combined with MLP#14 determined the sum of losses of MLP#13 and MLP#14. Combining this information allowed computation of the individual losses of MLP#13 and MLP#14. The loss of each of the other devices could then be computed by subtracting the loss of MLP#13 from the measured loss of the combination of that device with MLP#13, or by performing a similar calculation based on MLP#14; in fact, both computations were performed and the results averaged to determine the loss of those devices.

The unit-to-unit variation of the loss of the impedance matching pads at channel-30 frequencies was of interest because of their use in the splitter test setup. The pads were found to be quite well matched—with samples ranging from 5.79 to 5.84 dB at the frequency of TV channel 30.

All of the pads and both transformers were found to be flat to within 0.02 dB across the 6-MHz bandwidths of each tested channel (3, 10, and 30).

TV-channel-specific measurements of absolute loss of one impedance matching pad (MLP#12) were used in determining minimum signal at TOV because the actual signal level measurement did not include the loss of that pad. Those losses were 5.70, 5.73, and 5.82 dB, respectively, on channels 3, 10, and 30.

The frequency-dependent measurements of the loss of one impedance-matching transformer (TT#1) were used in determining the frequency response of the splitter test configuration to the 50-ohm outputs (Pt5a and Pt8a).

Splitter Test Configuration

Because of the complexity of the splitter test configuration, which included amplifiers, a noise generator, a directional coupler, and splitters that were not a part of the simpler minimum-signal test configuration, additional tests were performed to verify its performance. The tests evaluated the frequency response (including the potential effect of errors in input impedance of the TVs), port-to-port matching, signal and noise spectral characteristics, and signal quality.

Frequency Response and Effect of Mismatched Loads

The splitter test configuration (Figure A-1) provided nine identical output ports, each of which could be configured for connection to a 75-ohm device (the antenna port of a consumer DTV) or to a 50-ohm device (vector signal analyzer, spectrum analyzer, or an instrumented reference receiver having 50 ohms input impedance). Configuration of each port was performed by connection of either an impedance-matching pad (50 to 75 ohms, 5.8 dB nominal power attenuation) or a 50-ohm pad (6 dB ±0.5 dB) at the final output of the port (end of the 25-foot low loss cable). The ports were designated Pt1, ... Pt9 when matched to 75 ohms. A suffix "a" was added to the designation of ports matched to 50 ohms. Only two ports were ever configured for 50 ohms during the reported tests: the fifth port (Pt 5a), which always served as the measurement port; and the eight port (designated Pt8a, when so configured), which was used to connect to the instrumented, 50-ohm input receiver designated 2000REF for one set of tests.

Figure A-3 shows the frequency response of the entire test setup from the output of the ATSC signal source (PtA in Figure A-1) to each of the final output ports. For port 8, separate results are shown for the Pt8 and Pt8a configurations. During the measurements, all ports except that being measured were terminated in the appropriate impedance—either 50 or 75 ohms. The response of each port was flat to well within 0.1 dB (maximum – minimum) across the 6-MHz bandwidth of TV channel 30. The gain of each 75-ohm port matched that of the measurement port (Pt5a) within 0.2 dB.

A test was also performed to determine whether frequency response on one port would be significantly affected by impedance mismatches on other ports, since consumer TVs may not have carefully controlled input impedance. Figure A-4 shows three frequency response plots measured on Port Pt5a under three different load conditions for the other eight ports: ideal terminations (75 ohms), actual TVs (tuned to channel 30), and open circuits. With TV's as loads the frequency response across channel 30 remained flat to well within 0.1 dB. With open circuits on all eight ports, flatness degraded somewhat, but was still well within 0.2 dB across channel 30.

All of the above tests were performed by using a spectrum analyzer and tracking generator, as shown in Figure A-5. In all cases the tracking generator signal (connected through an attenuator pad to stabilize the impedance) was injected at PtB in Figure A-1 so that a 50-ohm source could be used. For frequency response tests of 75-ohm ports, the losses in TT#1, the impedance-matching transformer that normally connected the 75-ohm ATSC source to PtB, were included by using TT#1 to match the impedance of the selected port to the 50-ohm input of the spectrum analyzer. For frequency response tests of 50-ohm ports, TT#1 was omitted from the measurement, but its losses as a function of frequency (measured separately) were included in the computed frequency response. In all cases, the tracking generator signal—as attenuated by the 10-dB pad shown in Figure A-5—was measured by the spectrum analyzer as a reference in the frequency response calculations. All measurements were performed with the same spectrum analyzer settings (including input attenuation and reference level) in order to ensure accuracy of the computed frequency response function.)

Signal Spectrum, Noise Spectrum, and Signal Quality

Spectrum and modulation error ratio measurements indicate that a high quality test signal and spectrally flat noise were delivered to the output ports of the test setup.

Figure A-6 shows spectra of the injected signal and noise as measured at Pt5a during playback of the "Hawaii_ReferenceA" file from the RF capture player at a CNR of 15 dB. The spectra were measured with a 30-kHz resolution bandwidth, 300-kHz video bandwidth, RMS detection, and trace-averaging (in linear power units) of 8192 traces. (This averaging was performed across multiple loops of the test signal). The noise spectrum is flat across the 6-MHz bandwidth of TV channel 30 to within 0.34 dB (maximum – minimum) for the spectrum as shown and to within 0.11 dB when a 500-kHz smoothing width is applied to average out some of the randomness of the measurement. Similarly, the signal spectrum is flat across the 4.76-MHz wide "head" (i.e., flat part) of the ATSC signal to within 0.59 dB for the spectrum as shown and 0.38 dB when 500-kHz smoothing is applied.

Modulation error ratio (MER) measured by the vector signal analyzer during the tests of required CNR was a respectable 33 to 35 dB without including any equalization in the vector analyzer and 37 dB with equalization.

Other Checks

A test was performed to ensure that any impedance mismatch at PtC in Figure A-1 would not affect the level of injected noise from the noise generator through the resulting variations in impedance at the signal input to the directional coupler as the signal step attenuator was varied. The noise level step attenuator was adjusted to achieve -70 dBm noise level at Pt5a. Amplifier A2 was then replaced by a short circuit at PtC and the noise level at Pt5a was measured for two different settings of the signal attenuator—0 dB and 81 dB. The measured variation in noise power was only 0.01 dB.

To ensure that amplifier A2 (Figure A-1) was not operated in a non-linear region that might affect signal quality, the signal level at the output of A2 was measured during playback of the "Hawaii_ReferenceA" file. The measured level was 17.5 dB below the 1-dB compression point of the amplifier.

Signal-to-noise ratio of the signal path (excluding any noise generated by the RF player) was measured to ensure that amplifier noise (from A1 and A2 in Figure A-1) did not significantly affect results. SNR in a 6-MHz bandwidth was found to be 64 dB on channel 30.

TEST ISSUES

A few observations regarding issues that arose during the test program may be of value to others who perform DTV receiver performance testing.

Multipath Performance Testing Using the RF Player

After we had tested 16 DTV receivers against each of the 47 RF captures, visiting engineers from a DTV chipset developer (ATI Research) observed video errors on one of the TVs during playback of a few captures. Though all tested TVs were able to play some of the captures with no visible errors, the visiting engineers suggested that the errors observed on some specific captures indicated that the FCC's RF player was not functioning properly. This conclusion was based on two factors: (1) they had tested a TV with the same technology at their labs and found it had produced no visible errors on those specific captures; (2) they reported having had problems with several of their own RF capture players that produced visible errors which went away after calibration and repair of the player.

Based on these observations, we sent our RF player back to the manufacturer for repair and calibration; the manufacturer indicated that our problem had been caused by a ground plane error on one of the cards. After they replaced that card and recalibrated the unit, the difference was dramatic. A TV that had successfully handled only 10 of the captures with no visible errors before the repair was able to handle 31 of the captures without visible errors after the repair. We subsequently discarded all previous results and repeated all testing.

As an additional confirmation of performance of our RF player—in conjunction with our entire splitter-based test setup, ATI allowed us to test two DTV samples (subsequently identified as "upper tier" performers in Chapter 6) at their laboratories using their equipment. The net test results (number of captures played with no visible errors and number played with no more than two visible errors) at the FCC using our test setup with our repaired RF player matched those that we performed at ATI for one of the TVs. For the other TV, the tests at the FCC showed three more captures producing two or fewer errors (including zero errors), but showed two fewer captures producing no errors. Given the variability in results that sometimes occur between playback loops along with the subjective judgment in identifying visual errors, these differences were considered acceptable.

RF Source for Measurements of White Noise Threshold and of Minimum Signal

Our plan had been to use the RF player as an ATSC source only when performing multipath testing. An ATSC signal generator was to be used for testing of white noise threshold and of minimum signal at TOV.

In initial tests of 16 DTV receivers using the signal generator as a source, the white noise threshold of the best tested receiver was found to be 15.25 dB. This was slightly higher than the 14.9 to 15.0 dB that had been expected for the better-performing receivers; consequently, the generator was sent back to its manufacturer for calibration and checkout. Upon its return, retesting of that best performing receiver yielded a white noise threshold 16.0 dB—indicating degraded signal quality.

After the poor result with the signal generator, white noise threshold was measured again, but this time using the RF player and a laboratory-recorded DTV signal file designated "Hawaii_ReferenceA" as the signal source. The measured white noise threshold of that same receiver was then found to be 14.94 dB. Based on these results, the ATSC signal generator was replaced by the RF player, which was then used for all testing reported herein. (Previous test results were discarded and all tests were repeated.)

Getting DTV Receivers to Recognize a DTV Signal

The channel-selection "intelligence" of many DTVs combined with certain artificialities of laboratory-based testing to create some challenges.

With analog television, to receive a signal on a given TV channel you simply select that channel. With DTV, there is another layer involved channel selection. To simplify the DTV transition for the consumer, a DTV signal includes coding that tells the TV the channel number of the analog station that is associated with that DTV signal. In Washington, DC, for example, the DTV broadcast on channel 48 includes information linking it to an analog broadcast on channel 4. A TV viewer not aware of the digital broadcast on channel 48 can tune to a channel he or she may already view—channel 4—and the digital television will automatically set its tuner to channel 48 to select the digital broadcast containing the same programming as the viewer would have seen on analog channel 4.

To facilitate this extra layer in channel selection, DTVs include a channel scan function that is used on initial setup of the TV. The function causes the tuner to sequence through all TV channels searching for analog and digital signals. It creates a mapping from the analog channel numbers to the digital ones and may also identify available sub-channels on each DTV broadcast, since the DTV transmission system enables transmission of more than one program within a single RF TV channel. Many of the TVs will not allow a DTV signal to be received unless it has been identified by such a scan.

The laboratory tests described in this report created two types of anomalies—one associated with the tests of minimum signal at TOV and the other associated with multipath testing using the RF captures.

The minimum signal tests were performed on channels 3, 10, and 30. The available equipment allowed creation of the signal on only one channel at a time; consequently, any channel scan identified only one channel, and when the channel was changed for the next set of tests, the channel scan had to be repeated.

For the multipath testing, a less obvious problem occurred. All testing was performed on channel 30, so one might expect that a single channel scan on each TV would enable testing with all 47 captures. While this worked for some TVs, it did not for others. The original source material for the captures was recorded from eight DTV channels in two cities. Many of the receivers were "confused" by changing broadcast stations (from one capture to the next), even though the RF channel remained constant. Many would not allow selection of the signal as channel 30; instead, the signal had to be tuned indirectly by selecting the channel number of the analog broadcast associated with the recorded digital broadcast—which could only occur after a channel scan.

Thus, each time that an RF capture was loaded, if it originated from a different broadcast station from the last, steps had to be taken to ensure that each TV recognized the new signal. The necessary steps varied among the TVs. Some immediately displayed the new video. For others, simply pressing the channel up or down button caused the signal to be selected. For TVs requiring a new channel scan, some allowed the user to select a single channel number to rescan (channel 30 in this case), while other required a more time consuming rescan of all channels. For some TVs, even a complete rescan was not sufficient to lock in the new signal; unplugging the TV from its power source followed by a channel rescan was usually sufficient in those cases.

To save time in the multipath testing process, the captures were sorted by originating broadcast station before testing. This reduced the number of transitions between broadcast sources so that fewer channel scans would be necessary. To further assist in testing, the captures were sorted—within each originating channel group—to allow the more benign captures from a given broadcast station to be played first in order to lock the receivers onto each new broadcast station using a signal for which success would be likely. It was found, however, that during subsequent testing with captures exhibiting more challenging multipath conditions, some TVs would change channels—or even turn off—during the period when no recognizable signal was received. Consequently, it was often necessary to return to an easier capture from the same broadcast source at various times during the testing to ensure that the TVs were still locked on to that broadcast.

PROCEDURES

Test procedures applicable to the DTV measurements conducted for this report are shown below.

General

The following procedures apply to all measurements.

- Warmup
  - ◊ Allow all test equipment (signal and noise sources, amplifiers, measurement equipment) to warm up for a minimum of 2 hours before testing.
  - ◊ Allow all TVs to warm up at least one hour before testing
- Test equipment calibration
  - ◊ Before each measurement sequence using the spectrum analyzer, perform a full alignment—including RF alignment requiring an external cable connection to the built in calibrated source. (Spectrum analyzer is used only for measurements of test configuration parameters such as frequency response and output spectrum.)
  - ◊ Before each measurement sequence using the vector signal analyzer, invoke the "single cal" function to calibrate the instrument.
- Measurement of applied signal and noise levels
  - ◊ Use averaging times of approximately 21 seconds (1200 averages on vector signal analyzer) when measuring signal levels and ensure that the averaging interval begins just after the start of a playback loop on the RF player and ends before completion of that loop in order to avoid averaging across the loop restart.
  - ◊ For measurements of noise levels, use averaging times ≥ 21 seconds.
- Identifying visual errors in video
  - ◊ Allow the RF player to play the selected signal through at least three complete loops before making observations.
  - ◊ Do not count errors occurring at each loop restart of the RF player
  - ◊ Do not count errors associated with known recording defects due to dropped symbols (Appendix B)
  - ◊ Horizontal streaks occupying a single scan line are judged to be defects in video source material prior to conversion to MPEG format for broadcast and are not counted.
  - ◊ For an error burst lasting longer than one second, count the number of errors as the approximate duration of the burst in seconds.

White Noise Threshold Tests

Note that all measurements are performed using the vector signal analyzer (VSA), and all attenuator settings and measurements are entered into a spreadsheet that performs the required computations.

- Connect equipment as shown in Figure A-1
- VSA setup
  - ◊ Run DTV measurement software*
  - ◊ Set number of averages to 2000
  - ◊ Set broadcast channel 30
  - ◊ Execute "single cal"
  - ◊ Set amplitude range to -50 dBm (most sensitive range)
- RF player setup
  - ◊ Load "Hawaii_ReferenceA" file
  - ◊ Set output channel to 30
  - ◊ Set output level to -30 dBm
- Noise generator setup
  - ◊ Set the internal noise attenuator to 0 dB

* "Control Software for the HP89400 Vector Signal Analyzer for Measuring DTV and NTSC Signals", VSA5.BAS, Version 5.02, Gary Sgrignoli

- Measure VSA self noise by connecting a 50-ohm termination to the VSA input and performing a "long average power" measurement. (This value will be subtracted—in linear power units—from all subsequent measurements.).
- Connect the VSA to Pt5a (Figure A-1)
- Measure modulation error ratio (MER) as an indication of signal quality
  - ◊ Set noise attenuator to 81 dB
  - ◊ Set signal attenuator to point at which VSA indicates occasional clipping (typically 24 dB attenuation) in order to maximize signal to VSA-noise ratio
  - ◊ Measure MER four times and average the results. The measurements are performed without any equalization in the VSA.
- Set and measure injected noise level
  - ◊ Set signal attenuator to 81 dB
  - ◊ Adjust noise attenuator to the 0.1-dB step that most closely yields a "long average power" reading of -70 dBm
  - ◊ Measure the "long average power" twice. (Actual injected noise power will be computed by averaging these two measurements with two similar measurements performed after the TV tests and subtracting—in linear power units—the VSA self noise. Though the correction for VSA self noise is performed in the spreadsheet, the correction is essentially negligible because VSA self noise is about 27 dB below the injected noise level.)
- Set signal to a high level and take whatever steps are necessary to ensure that all connected TVs are tuned to the signal and producing a picture.
- TV tests. Repeat for each of the connected TVs (typically eight). Include receiver D3 in each test sequence as a consistency check.
  - ◊ Adjust signal level upward as necessary to obtain a picture
  - ◊ Adjust signal level downward until picture either drops out or exhibits a high visual error rate
  - ◊ Adjust signal level upward in 0.1-steps to achieve the lowest signal level that produces a picture that is free of visual errors for 10 seconds. Record this attenuator setting.
  - ◊ Adjust signal level upward in 0.1-steps as needed to achieve the lowest signal level that produces a picture that is free of visual errors for 60 seconds. Record this attenuator setting.
    - As a consistency check, the spreadsheet computes difference between attenuator setting in previous step and current attenuator setting. This difference is typically between 0 and 0.2 dB.
  - ◊ Perform "long average power" measurement as described below. This measurement represents the total of the injected signal level, the injected noise level (typically about 15 dB below the injected signal level), and the VSA self noise (typically about 42 dB below the injected signal level).
    - The measurement should be initiated near the end of a playback loop, so that—following the initial operations performed when "long average power" is selected—the actual long integration will begin just after the start of the RF playback loop. The reading of average power should be taken just before the end of that playback loop.
    - As a consistency check, the spreadsheet calculates the sum of the signal attenuator setting and the measured power level. This sum should be nearly constant across all TV measurements.
    - Spreadsheet calculates injected signal level by subtracting—in linear power units—the injected noise level and the VSA self noise from the measured power. The injected noise level subtraction typically results in a correction slightly larger than 0.1 dB. The VSA self noise correction is negligible.
    - Injected signal-to-noise ratio (SNR), termed the carrier-to-noise ratio (CNR) in this report, is computed. (A subsequent adjustment is made for TV self-noise—based on measurements of minimum signal at TOV; however, this correction is essentially negligible.)
  - ◊ Confirm that the measured level is sufficient for relocking on to the DTV signal.
    - Reduce signal level by 20 dB for 20 seconds. Return to previous level and verify that the TV recaptures the signal.